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OPTIMISATION OF FUEL CONSUMPTION BY TAGUCHI METHOD IN LOGISTICS SYSTEMS

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ABSTRACT

Research studies on fuel consumption of logistics systems for developing countries is relatively less explored in par with developed countries. Day by day, the consumption of fossil fuels is increasing due to dense traffic, heavy cargo loads, evolving of e-retailing services, erratic drivers etc. This research work considers six key factors for analysis, with an intent of reducing fuel consumption of Logistics Service Providers(LSP). The data collected from logistics service providers, located in India through email; and then it is analysed using Taguchi Method, to find the high influencing factor on fuel consumption to the greater levels. The identified six factors are dead weight of vehicle, mileage per litre, percentage of fuel spent in idle time, span of distance covered, payload of vehicle and average time spent in traffic. The results are obtained based on the condition: smaller the better and it is validated by the LSP.

KEYWORDS: Fuel Consumption, Taguchi Method, Logistics Service Providers (LSP), Green Logistics & Sustainability

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Original Article

1. INTRODUCTION

Traditionally, logistics service selections have been impelled by minimizing cost, maximizing profitability, or achieving customer service targets. As companies are including the sustainability dimension into their business objectives, it provides a soaring interest in curtailing the social and environmental impact of their product and operations. Since 2000, many Logistics Service Providers (LSP) are inching towards developing mobility; which are sustainable and demands less fuel. This research article, did a detailed analysis on reducing the fuel consumption of trucks; involved in transporting food grains from farmers to storehouses and then to the Distribution shops. Six factors of Fuel consumption, are reckoned to optimize it by Taguchi Method.

During the early twentieth century, the global economy coined new terms such as: globalized marketing, market liberalization, Technology outsourcing, Knowledge outsources and Process outsourcing. It increases the dependency of every business activity on logistics. The key objective of logistics is to deliver goods to the customers with high effectiveness and efficiency. Effectiveness (Liu Ping, 2009) is the process of merging logistic process with the company's objectives whereas efficiency is the process of evaluating the logistic performance (Lijmatainen. H, et al, 2012) by various metrics.

Moreover, the depth of investigation of logistic activities, happened in developing countries such as India and Asia Pacific is slightly lower than the developed countries namely: the US and Europe. Therefore, this article

investigated on a case study of a logistic activity happened in India.

The objective of this article is to: design an L27 orthogonal array; Measuring the deviation between experimental value and calculated value (based on Taguchi method) for fuel consumption; Identifying the optimum parameter settings for achieving low fuel consumption.

2. LITERATURE REVIEW

This section summarizes the functions of logistics service providers and the key aims of green logistics. Moreover, it also provides a light on the effect of fuel consumption.

2.1 Functions of Logistic Service Providers (LSP)

Logistic service providers (Perotti. S, et al 2012) are said to be third-party logistics; wherein the LSP (Lieb. K. J, Lieb.R.C.2010; Fleiscmann. M, et al, 2000) is dealing with freight forwarding, Transportation, cross-docking, storage, preservation, and inventory. However, transportation (Anable et al 2012; Ceren Altumas et al, 2013; Geberit annual report, 2015) was the primary source for emission which includes 13 percent of greenhouse gas emissions and 24 percent Carbon dioxide emissions across the world, in the year 2008. Therefore, logistic service providers are also recommended to develop logistic centers of excellence (ITF, 2009) which incorporates strategies namely: developing green corridors for transportation (Furtado, 2013), utilizing alternative modes of transport (like railways and ships) to reduce carbon dioxide emission (Zhu.Q.J. et al, 2008; Maibach et al, 2008) and to establish shipping centers outside the city (Lindstad and Sandars, 2014)

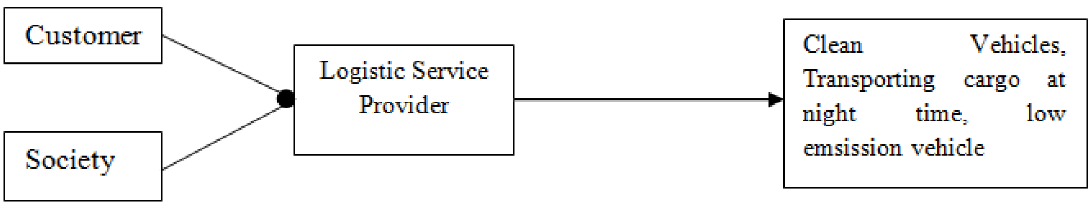


Figure 1: Functions of Logistic Service Providers

2.2 Key Aims of Green Logistics

Green logistics (Lee et al, 2008; Rodrigue. J.P et al., 2001; Sbihi & Eglese, 2007) is defined as a process of aligning environmental performance (Ping. L, 2009) of suppliers with end-user demands. It is also a measure, to evaluate the environmental impact (Irina Harris et al, 2018) of distribution strategies. The key green aims (Zhu & Sarkis, 2004) are formulated to develop a better sustainable logistics such as: reduction of oil & fuel consumption (Figure 2), Energy consumption reduction (Jackeline Rios-Torres et al, 2018); use of recyclable resources rather than depleting resources (Zhang et al 2014); mitigating the usage of toxic chemicals, production process modification; reduction of operating cost (Jan.H. Havenga et al, 2018); Greenhouse gas emission reduction (IEA-2010; Sebestian M.R. Dente et al, 2017)

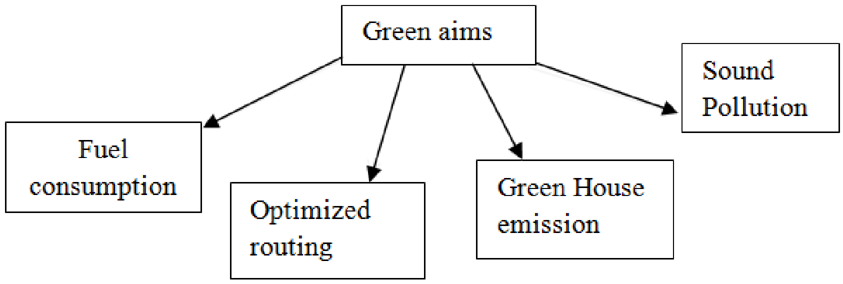


Figure 2: Key Aims of Green Logistics

2.3 Fuel Consumption

Fuel consumption is defined as the product of length of distance covered by a vehicle and the amount of fuel consumed per kilometer, and it will also be expressed in liters or in gallons. Fuel consumption in vehicles will be influenced by a few parameters, namely: wind speed, Tire inflation (or) deflation, than the prescribed values, Half-released brakes, frequently engaged clutches, Partial combustion of fuel during winter seasons, and idling time of engines such as engine initiation/ warm-up moments during traffic signals, crowded roads and so on.

The gaps identified from the literature review are

- During the yesteryears, the huge volumes of work were done for reducing greenhouse gases in vehicle emission and also to develop vehicles fuelled by the renewable resources.
- Moreover, three-fourth of the work done in the logistics domain is focused towards passenger cars and trucks used in developing nations.
- The work on fuel consumption optimization in developing countries are less. Furthermore, the speed of trucks in a growing economy (India) has less than 20 Kmph, whereas it reaches 50 Kmph in developed nations (Europe)

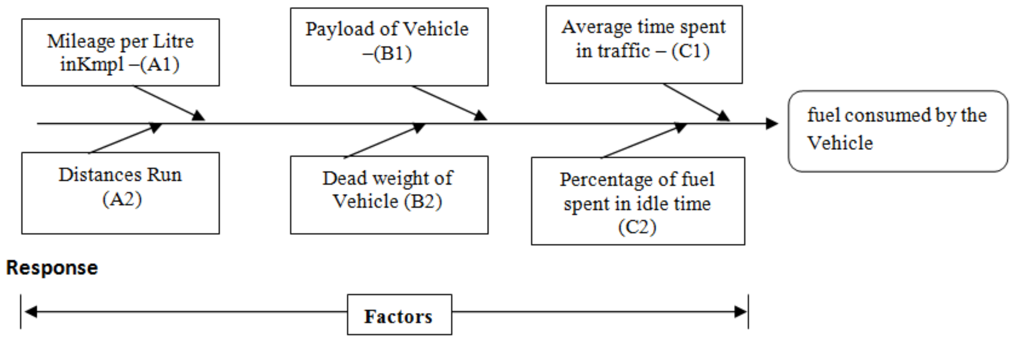
3. METHODOLOGY

Many methods are used for optimising fuel consumption, such as Response surface methodology, Taguchi method, Multi Factor Analysis. Out of which, Taguchi method is used in this research as it reduces the number of experiments and easy adaptability. Vincent. H & Udaya Kumar, (2012) have studied a single cylinder 5.2 KW diesel engine and optimized using Taguchi design. Key parameters identified for their investigation are: Clearance volume, Valve opening pressure, Nozzle-hole diameter, Static injection timing and load torque and the responses observed are Nitrous oxide (NOx Emission) and brake specific fuel consumption. It is iterated in four levels. Moreover, an another group have analyzed (Win.Z et al, 2005) the following parameters namely: Speed, load, injection timing, plunger diameter, nozzle hole diameter, and nozzle tip protrusion by Taguchi method and the responses are: Engine noise and brake specific fuel consumption. They identified a high performing key parameter which has major influence on the response by Taguchi method. Using L9 orthogonal array, group of researchers have identified an influencing parameter from the basket of three parameters namely: Exhaust gas rate, fuel injection timing and pressure which will provide a bias on the outcome (Saravanan et al, 2010). The outcome of this project is Nitrous oxide emission from the Fuel engine. Taguchi method will find three results for a problem, namely: Identifying a high performing key factor from the cluster of three key factors; Optimizing the key parameter values to acquire the outcome at preferred condition (Smaller the better/larger the better.);

Estimating the response values and calculating the deviation from the experimental value.

3.1 Key Factors Identified

The potential key factors which can influence the fuel consumption of trucks are listed and classified, based on the perspective of automobile experts. Key factors are plotted in Herringbone diagram and displayed.



Note: *Response* denotes an output (dependent) variable, whereas *Factor* denotes an independent variable

Figure 3: Herringbone Diagram

The extensive study of a book (Green logistics by McKinnom), leads to the development of a data tracking sheet (Appendix: Section-A). This data sheet is designed to record the driving behaviour (Elisabet Bjorney and Gudmundur. F. Ulfarsson, 2015), of a truck driver, which includes the amount of time spent in the traffic (Wardman. M., 2004), Mileage gained by Vehicle for a litre (J.I. Huertas et al, 2017), Total fuel spent for a trip, Exhaust gas analysis of the Vehicle (Harmful gas presence in the exhaust), Distances covered per day.

3.2 Problem Methodology

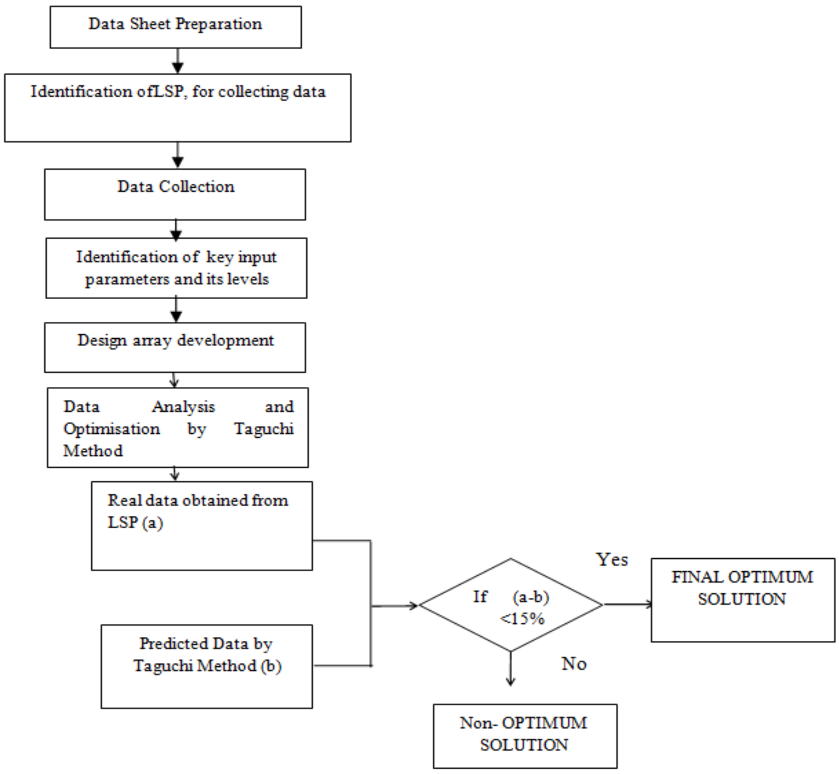


Figure 4: Problem Methodology

4. CASE STUDY

4.1 About Civil Food Supplies

The Civil food supplies department is a wing of the Government of India, which supports the poorest Indian citizens with food grains and all essential items required for daily living by either free or in meager costs. It is executing this activity in a highly systematic way. The entire activity is descending down into two halves namely, Primary phase and secondary phase. Primary phase (Figure 5) includes: Procuring grains from direct farmers at affordable cost and then it will be inspected and transferred to God owns for storing in conditioned temperature. Secondary Phase (Figure 6) includes: PDS shops will raise a demand claim of food grains based on customers need and the God owns will respond to this demand by supplying the needs of PDS (Public Distribution Shops). The third party logistics involved in both phases and they are: Transferring food grains from farmers to God owns and then God owns to PDS shops.

Primary Phase

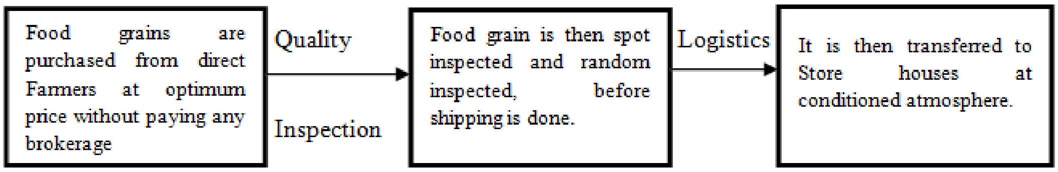


Figure 5: Primary Phase of Food Supplies

Secondary Phase

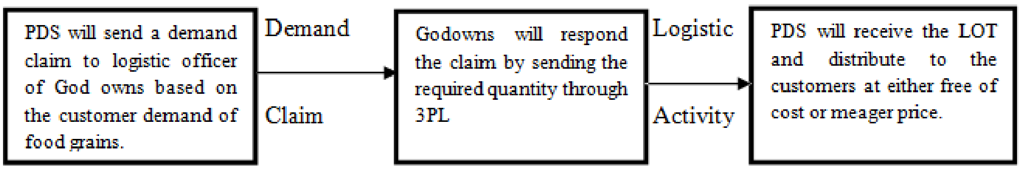


Figure 6: Secondary Phase of Food Supplies

The First phase of food grain collection will be happening during harvesting seasons, namely: March and May of every year; whereas the second phase of distributing the food grains will be done throughout the year. The Primary focus of this article is to capture the efficiency of logistic service providers, used in the food supply chain.

4.2 Data Collection

The parent table is then modified and interpreted in vernacular languages, to make it user-friendly. The table is customized based on the inputs, received from academic and logistic experts. Moreover, suitable industries have to be identified for collecting data. The identified are a *logistic wing of Civil Food Supplies, Department of India*; and also a *transportation department of an elementary school*. These premises are located in a town in Southern India. The designed table (Figure 7) is then sent for collecting data. The data arrived after a time span of eight months. It is processed and analysed, by using Taguchi Method; and subsequently, the results are studied thoroughly.

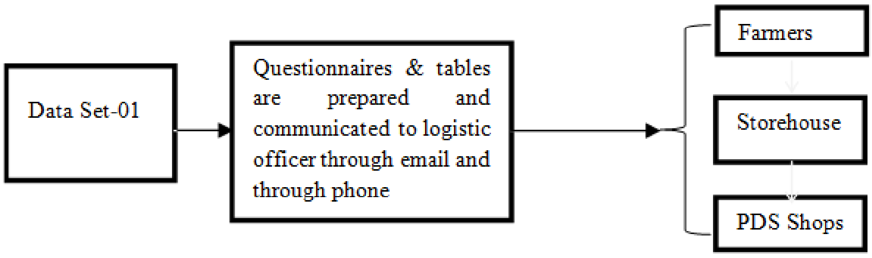


Figure 7: DATA Collection Process-I

Similarly, another data set (Figure 8) is collected from an academic institution. It observes the moment of a school van while it is picking the student until it drops them in their homes.

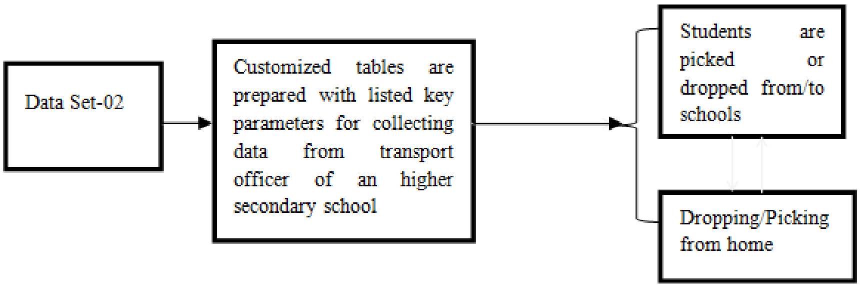


Figure 8: DATA Collection Process-II

Table 1: Technical Specifications of Trucks Used by LSP

SNO	Description	Vehicle-A	Vehicle-B	Vehicle-C
1	Dead Weight of Truck	6500	6700	7000
2	Payload of Truck	6000 -7500 Kg	13000- 14000 Kg	13000- 14000 Kg
3	Power of Truck	130 HP@2400 rpm	130 HP@2400 rpm	180 HP@2400 rpm
4	Torque of Truck	450 Nm, 1250-2200 rpm	450Nm @ 1400-2000 rpm	660 Nm@1200-1900 rpm
5	Transmission	6 Speed gear box	6 Speed gear box	6 Speed manual
6	Max. Speed	84 Kmph	95 Kmph	78 Kmph
7	Fuel Tank Capacity	208 litres	200 Litres	400 litres
8	Ground Clearance	260 mm	232 mm	260 mm
9	Engine Cylinders	4	4	6

The vehicle used and its configurations are tabulated in Table 1. Three configurations of vehicles are deployed in day to day service to connect Store houses with the PDS shops. Usually the time of transit happens in the early morning (0600 to 1100 AM) or in the post lunch session (0300 to 0600 PM.)

4.2 Data Analysis: Taguchi Method

The steps involved in Taguchi Method are

- The collected data are sorted strategically, and then response variable and control parameters are selected from the available data.
- Taguchi design is done, by identifying the optimum orthogonal array for the given inputs.
- The levels of each factor are found out, based on the available data.
- Experimental results are analysed and based on the result, the optimized values for each factor was listed.

- The obtained results are then compared with the experimental values.

In Taguchi method, the L27 (6 X 3) orthogonal array is selected for analysis. The inputs are: six factors; three levels, 27 iterations are taken; Smaller the better have opted for the ranking method. Entire lot, of Taguchi calculation (Table 6) is done by Minitab software tool.

Table 2: Selected Input Parameters at Three Levels

Sno	Controlled Factors	Level-1	Level-2	Level-3
1.	A : Dead weight ofVehicle(Kg)	6500	6750	7000
2.	B. Mileage per litre (Kmpl)	2.77	3.635	4.5
3.	C: Percentage of fuel spent in idle time (%)	7.5	18.75	30
4.	D: Span of distances covered (Km)	8	15	32
5.	E: Payload of Vehicle (Kg)	6000	13500	14000
6.	F: Average time spent in traffic (minutes)	5	15	20

The levels of a factor are defined as multi range of (finite) values, which can stimulate the response of an experiment (Fuel consumption). In Table 2, each parameter is grouped with three labels, namely: Level-1, Level-2, and Level-3. Taguchi will identify the balanced combination of all three values, to get the minimum response (i.e., lowered Fuel combination– smaller the better)

Table 3: L27 Design Array of the Experiment

SNO	A	B	C	D	E	F
1	6500	2.77	7.5	8	6000	5
2	6500	2.77	7.5	8	13500	15
3	6500	2.77	7.5	8	14000	32
4	6500	3.635	18.75	15	6000	5
5	6500	3.635	18.75	15	13500	15
6	6500	3.635	18.75	15	14000	32
7	6500	4.5	30	32	6000	5
8	6500	4.5	30	32	13500	15
9	6500	4.5	30	32	14000	32
10	6750	2.77	18.75	32	6000	15
11	6750	2.77	18.75	32	13500	32
12	6750	2.77	18.75	32	14000	5
13	6750	3.635	30	8	6000	15
14	6750	3.635	30	8	13500	32
15	6750	3.635	30	8	14000	5
16	6750	4.5	7.5	15	6000	15
17	6750	4.5	7.5	15	13500	32
18	6750	4.5	7.5	15	14000	5
19	7000	2.77	30	15	6000	32
20	7000	2.77	30	15	13500	5
21	7000	2.77	30	15	14000	15
22	7000	3.635	7.5	32	6000	32
23	7000	3.635	7.5	32	13500	5
24	7000	3.635	7.5	32	14000	15
25	7000	4.5	18.75	8	6000	32
26	7000	4.5	18.75	8	13500	5
27	7000	4.5	18.75	8	14000	15

The values in table 3 are the iterative values for 27 iterations (L27) with six different factors. These values are processed by Taguchi and then the optimum values are extracted.

Table 4: S/N Ratio Formulations

Sno	S/N Ratio Configuration	Formulae
1.	The Smaller-The better	S/N = -10 log ($\sum Y^2/n$)
2.	The higher-The better	S/N = -10 log ($\sum(1/Y^2)$ /n)
3.	The more nominal-the better	S/N = -10 log ($\sum Y^2/S^2$)

The formulae for calculating the Signal to Noise ratio values are given in the Table 4. This article follows the condition Smaller the better. Hence, the formulae (S/N = -10 log ($\sum Y^2/n$)) is used in calculating those values.

A: Dead weight of Lorry (Kg)

B. Mileage per litre (Kmpl)

C: Percentage of Diesel spent (%)

D: Span of distances covered (Km)

E: Payload of Lorry (Kg)

F: Average time spent in traffic (minutes)

Table 5: Analysis of Variance for S/N Ratio

S.No	FACTOR	Seq SS (S)	DOF (f)	Adj MS (v)	F	Contribution (%)
1.	**A : Dead weight of Vehicle (Kg)**	4.3597	2	2.1798	0.64	**6.80**
2.	B. Mileage per litre (Kmpl)	0.3159	2	0.1579	0.05	0.492
3.	**C: Percentage of Fuel spent in idle time**	9.3645	2	4.6822	1.37	**14.607**
4.	D: Span of distances covered (Km)	0.8101	2	0.4050	0.12	1.26
5.	E: Payload of Vehicle (Kg)	0.2737	2	0.1369	0.04	0.4269
6.	**F: Average time spent in traffic (minutes)**	1.1317	2	0.5659	0.17	**1.765**
7.	Residual Error	47. 8516	14	3.4180		
8.	**Total**	**64.1071**	**26**			

Based on the contribution percentage of Table 5, the factors are ranked. The Contribution percentage is defined as the ratio of the Sequential Sum of squares to the Total Sum. Factor-C records highest contribution (14.607 %), Dead weight of the Vehicle succeeds the former one and the third ranked factor is the average time spent in traffic. The above three factors are having more influence on the response. To control the response, these three factors have to be kept in optimized position.

Table 6: Response Table for Signal to Noise Ratios (Smaller is better)

Level	Dead Weight of Vehicle (A)	Mileage per Litre (B)	Percent of Fuel Spent in Idle Time (C)	Span of Distances Covered (D)	Payload of Vehicle (E)	Average Time Spent in Traffic (F)
1	-18.06	-17.55	-18.29	-17.27	-17.60	-17.37
2	-17.36	-17.62	-16.87	-17.66	-17.37	-17.37
3.	-17.12	-17.37	-17.38	-17.61	-17.57	-17.80
Delta	0.95	0.26	1.42	0.39	0.23	0.44
Rank	**2**	5	**1**	4	6	**3**

The response values of each parameter are calculated by the formula: S/N = -10 log ($\sum Y^2/n$) based on the condition: Smaller the better. Based on the highest scalar value of Delta, the ranking is done. Table 5 ranks the parameters based on the contribution percentage whereas the Table 6 ranks based on the Delta value. In both tabular values, Parameter-C, A, F occupies the first, second and third ranks respectively.

4.4 Data Validation

Validation of data for Taguchi method (Table 7) is done by comparing the parallel process values computed from the Taguchi method and experimental runs

Table 7: Experimental Values and Predicted S/N Ratios for the Fuel Consumption

SNO	Fuel Consumption (LITRES)		Change (%)
	Experimental Values (E)	Predicted Optimum Signal to Noise ratio (P)	
1	18.6697	18.575	0.51
2	18.6393	18.3533	1.53
3	18.5986	18.9794	2.05
4	18.5782	17.6149	5.19
5	17.2426	17.3932	0.87
6	17.2068	18.0194	4.72
7	17.1587	17.8205	3.86
8	17.1346	17.5988	2.71
9	19.351	18.225	5.82
10	19.2758	16.7941	12.87
11	15.6781	16.997	8.41
12	15.5919	16.7546	7.46
13	13.9794	17.0417	21.91
14	18.6697	17.2446	7.63
15	18.6393	17.0022	8.78
16	18.5986	18.0854	2.76
17	18.5782	18.2882	1.56
18	17.2426	18.0458	4.66
19	17.2068	17.5433	1.96
20	17.1587	16.8776	1.64
21	17.1346	17.0792	0.32
22	19.351	18.4782	4.51
23	19.2758	17.8125	7.59
24	15.6781	18.0141	14.90
25	15.5919	16.4569	5.55
26	13.9794	15.7913	12.96
27	18.6697	15.9929	14.34

Data validation (Table 7) of Experimental runs value is compared with PSNR (Predicted Signal Noise ratio) and the percentage of deviation is mentioned in the last column. The percentage of Change is calculated by the formulae: {(E-P)/E} where E is the experimental values and P is the predicted signal noise ratio.

Table 8: Optimum Parameter Settings for Low Fuel Consumption

S.No	Controlled Parameters	Fuel Consumption
1.	A : Dead weight of Vehicle (Kg)	7000
2.	B. Mileage per litre (Kmpl)	4.5
3.	C: Percentage of Fuel spent in idle time	18.75
4.	D: Span of distances covered (Km)	8
5.	E: Payload of Vehicle (Kg)	13500
6.	F: Average time spent in traffic (minutes)	5
	Predicted optimum value	15.7913 litre
	Experimental value	13.9794 litre
	Change in deviation	12.96 %

The optimum parameter values for low Fuel consumption are captured in the Table 7. The values of this table (Table 8) are extracted from the graph (figure 9). The graph (figure 9) was processed with the response condition: smaller the better. To get the lower response from the graph (figure 9), all the factors selected are to be in higher values. In this case, the optimum parameter settings based on the above said principle is: **A3-B3-C2-D1-E2-F1**. These parameter values are optimized experimental values which are captured in the 26th iteration of Table-3 & Table 7. The experimental value attained is the smallest value of all the 27 iterations. The optimum parameters achieved (based on the principle: Smaller the better) are: A3 (**7000**) - B3 (**4.5**) - C2 (**18.75**)-D1 (**8**)-E2 (**13500**) - F1 (**5**) value. The predicted Optimum Signal to noise ratio and Experimental value are extracted from the table-7 (26th Iteration).

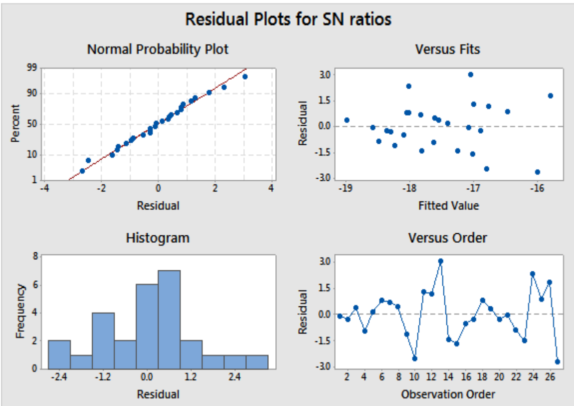


Figure 9: Main Effect Plot for Signal to Noise Ratio (*Taguchi Method- Smaller the better)*

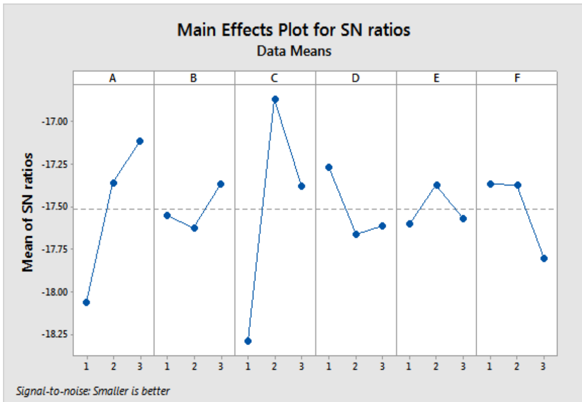


Figure 10: Residual Plot for Signal to Noise Ratio (*Taguchi Method- Smaller the better)*

NOTE: Notations of **A1, B1, C1, A2, B2, C2** are given in Appendix Section-B

5. RESULTS

Graphs plotted, in figure-IX are based on the level values of each factor, recorded in table 6. If a line is horizontal, then the main effect of that factor is very low. In the figure 9, factor-f (average time spent in traffic) has a less direct influence on the outcome (i.e., the interaction of this factor with the adjacent factor is high.) If a line is vertical, then it's the main effect has more influence on the outcome. In the plot for SN ratio (figure 9), level-2 of factor-C (Percentage of Fuel spent) has the peak point.

The first micrograph (normal probability plot of Figure 10) checks the prediction that all the data are normally distributed or not. As most of the points are populated around the straight line, then it predicts that the data obtained are normally distributed. The second micrograph (Residual versus fits plot of Figure 10) investigates that the model developed

is satisfying the assumptions made. The three checkpoints includes: Uneven spreading data; Points populated away from zero; Points located away from other points in X-axis. But the graph attained (Residual versus fits plot) is contradicting to the three checklists and hence it satisfies all the assumption made.

The third micrograph (Histogram of residuals of Figure 10) has to align with checklists includes: whether it has a long tail in one direction and each bar is far away from other bars which signify high skewness of data and includes the outliers respectively. But it contradicts the two checklists with the ground reality that it has even tails across the data and each bar is evenly placed which concludes that data is not either highly skewed or no outliers are included. The fourth micrograph (Residuals versus order plot of Figure 10) is to identify that the residuals are independent or not. If the data plotted are not having trends, then the residual points are identified as independent. But the graph plotted shows that it follows the trend and it is correlated and hence the factors are not independent.

6. DISCUSSION OF OUTCOMES

The Analysis of data collected from mass cargo transporters done by an optimizing tool (Taguchi method), recommends that: parameters *Percentage of fuel spent in idle time, Dead weight of the Vehicle and Average time spent in traffic* are the top three key parameters which can bias the response to the greater extent. *Percentage of Fuel spent in idle time* can be mitigated by switch off the running engines during lengthy time span signals, and in lower time signals, try to disengage the gears and avoid pressing clutches. *Dead weight of the vehicle i*s reckoned as the second influencing factor in response. Logistic service providers (LSP) have to investigate on the quantity of cargo to be transported, before signing the business contract. Based on the enquiry, the Vehicle size and transit frequency can be decided. Half truck load has to be eliminated, by purchasing the truck space from other LSP's who are transporting the cargo on the same routes, as prior one. *Average time spent in idle time* can be mitigated by: diverting the travel route to less dense traffic roads, opting out the night trips instead of day trips, utilizing the bye-pass roads instead of city roads, or by having a lesser distance gap between source and distances. Truck drivers have to be given with training in the time frequency of every six months. LSP's have to introduce incentive measures and promotion policies to motivate the drivers who consumes less fuel to cover longer distances. In the recent days, even the vehicles are incorporated with air chillers which can run on green energy.

7. CONCLUSIONS

This work provides a consumption analysis report, in the context of the Indian road scenario. Data is collected by the survey method, and then analysing is done with Taguchi design and the plotting is done by a tool Minitab (Taguchi Method) for acquiring results. The experiment results are then validated with simulated results. The results attained are shared with the mass cargo transporter of Civil Food Supplies Department, for the betterment of future society. This work can be further proceeded with dedicated cargo, specific truck driver and on different time slots and various terrains to understand the driver and vehicle efficiency.

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APPENDIX SECTION

SECTION-A:

Data Sheet to capture driving behavior

LOGISTICS TRACK SHEET

DATA TAKEN ON (DATE):			LORRY DEAD WEIGHT (KG)	
			LORRY NO.	
			DRIVER NAME & MOBILE NO:	
			ENGINE MODEL (YEAR) & MAKE:	

SNO	ODOMETER READING (INITIAL)	PAYLOAD OF LORRY (KG) - empty/full	ODOMETER READING (FINAL)	DISTANCE COVERED= (OD-final - OD Initial)	Mileage given by lorry	Time Spent in traffic	Amount of fuel spent in traffic	Total fuel spent for the specific distance	Emission norms of Lorry (eg. % of CO, % of Sulphur)	Mean emission norms per kg of pay load